Konstruktion
Zeitschrift für Produktentwicklung und Ingenieur-Werkstoffe
Special Print from No. 4 (2006)

Electrochemical Machining (ECM) Provides Creative Latitude

Designing without Manufacturing Process Limitations

The more complex the shape, the more cost-effective the process: Especially where workpieces of hard or smeary and thus difficult-to-machine materials are concerned, electrochemical machining (ECM) shows what creative latitude many a design engineer could enjoy, if they were familiar with the potential of this technology. Neither complex geometries nor undercuts are any problem for the ECM process. On the contrary, homogeneous structures, crack-free surfaces and safely predictable workpiece properties are standard.

Picture 1

General view: High-pressure turbine disk made of a nickel-based alloy. Diameter: 500 mm. Picture: Rolls Royce

Electrochemical machining of metal parts does not produce recast layers or burrs. Unlike other processes, such as electro-discharge machining (EDM) or high-speed cutting (HSC), ECM leaves the surface structures unaffected and unaltered. ECM is an imaging process, in which the shape of the tool is imparted to the workpiece material by a contactless electrochemical process which creates perfect geometries. Neither flank pressures nor surface deformations or cracks and thus weak areas are produced. Especially where safety requirements are high, as in turbine construction, the process pays off.

Workpiece hardness is irrelevant

ECM is basically suitable for machining all electrically conductive materials.

Even titanium or "smeary" materials containing up to 60% nickel pose no problem. Workpiece hardness is no consideration, as the process does not remove material mechanically, but uses an electrochemical process that takes place at maximum temperatures of between 60 and 80°C. The only mechanical load occurring during the process comes from the hydraulic pressure used to pump the electrolyte solution around the workpiece. That pressure is in the range of 5 to 15 bars. Thus no microcracks, hardness increases or other changes occur in the material structure.

Classic fields of application are machine and plant construction (profiling of roller mills and roller presses), aviation (turbine disks and casings), military engineering (tail planes, wings),

power plant components (for instance rotor disks as well as special mesh screens for nuclear power plants), automotive industry (antilocking brake systems (ABS), antislip control systems (ASC), hubs, piston bottoms), toolmaking (dies and molds) as well as medical

engineering (tablet rollers or protheses).

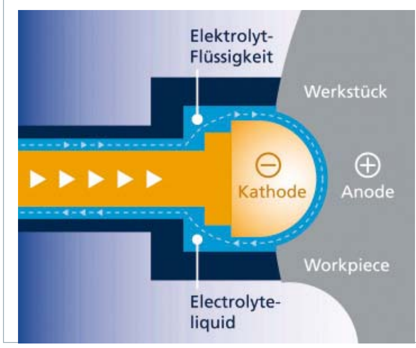
Thus ECM permits arched surfaces to be undercut or internally machined, which rotating tools are unable to do due to their mode of operation (Pictures 1 and 2). The inlet and outlet contours of the cooling passages shown in these pictures are rounded off simultaneously with the ECM process. ECM has firmly established itself in this domain, for it is an imaging process using up to three NC axes. It thus recommends itself for almost any type of freeform surface. This flexibility results primarily from the tool, i.e. the electrode.

In the ECM process, large-surface parts are machined with a maximum power consumption of 20 kA at 10 to 20 volts DC. Single and series parts with minimum surface areas of 25 mm or minimum part sizes of 20 mm x 20 mm x 20 mm can be machined. The largest workpiece which the contract-machining company Köppern GmbH+Co KG, based at Hattingen, Germany, has so far machined was a turbine rotor disk shaft measuring 3,200 mm in length and 800 mm in diameter (Pictures 3 and 4). The maximum component size is generally specified as 1,500 mm diameter x 2,500 mm height, weight: 5000 kg.

All contours machined by ECM are completely free from burrs, the surface quality being governed primarily by the type of material used

Electrochemical Machining

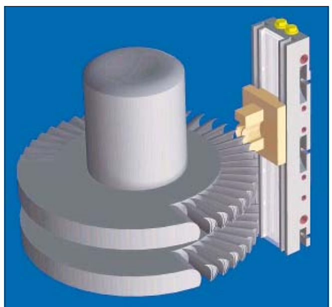
Electrochemical machining (ECM) is an imaging, eroding process, in which the tool and workpiece function as electrodes that are connected to the positive and negative poles of a
10 –20 V DC voltage source.
There is a gap of between 0.05 and 2 mm between the tool and workpiece, through which an aqueous electrolyte solution is pumped. As the tool advances – advance rates of between 0.5 and 10 mm/min are standard – the workpiece material is dissolved locally due to the electrochemical processes taking place in the machining gap, causing the part to assume the positive shape of the tool. The surface structure of the workpiece remains unaffected. The maximum process temperature is 80°C.



Principle of operation: ECM is an imaging process, in which the tool shape is imparted to the workpiece material by a contactless electrochemical process that generates perfect geometries.
Graph: Köppern

Picture 2

Detail: Rotating turbine bucket shoe with arched, elliptical cooling passages, 6.5 mm each
Picture: Köppern



Picture 3

ECM simulation of a turbine wheel of X22CrMoV21: The material is removed from the bucket crown down to the foot.
Graph: Köppern

and the machining direction. If hard metal is machined, for example, the carbides contained in the metal are not electrically conductive, while the metallic matrix in which they are embedded is. As a result, the machined hard metal surface is coarser than what would be obtained with continuously electrically conductive workpiece materials and uniform erosion.

On the other hand, the front gap – which is the distance between the electrode and the workpiece in machining direction – is between 0.02 and 0.1 mm, which is very small and makes for extremely accurate machining. The surface quality is correspondingly high. However, in the side gap, which may be up to 2 mm wide, there may be some waviness caused by the flow conditions. The average surface roughness is specified as R_a = 0.5 µm or R_z = 3 to 4. The achievable surface quality is thus somewhere between the quality levels obtained by finish milling and fine finishing. In the area of the front gap, even R_a = 0.1 µm may be achieved.

Regardless of the workpiece material, the average dimensional accuracy is 0.1 mm. However, exact tolerances can be specified only if the specific component to be manufactured is known. Here, the decisive factor is the overall relationship between the material and the dimensional specifications, between the number and location of the ECM contours and between the machining strategy and the tool specifications.

Unrivaled advance and erosion rates

ECM is suitable to machine all workpiece materials that are electrically conductive. The material is removed without any contact between the workpiece and the tool. As a result, the geometric reproducibility is close to 100%. The hardness of the workpiece material is of secondary importance. At machining temperatures of 80°C maximum, the process does not thermally stress the material nor does it increase the material hardness or produce recast layers – molten material that leaves layers of very small fragments and suspended material on the surface. Thus the process avoids the formation of cracks in workpiece pockets and recesses.

At 0.8 to 10 mm/min., the machining advance speed is unrivaled and results in material erosion rates that are 30% to 50% faster than what can be achieved by electrodischarge machining (EDM), for example. The machining quality is entirely independent of the operating personnel. The tool service life is theoretically unlimited, as the electrode operates without contact with the workpiece. It will consequently not wear out

Picture 4

In the ECM process, even sharpening the crown front is done in the same workpiece clamp.

Picture: Köppern

even after thousands of machining operations and many years of use.

The process offers economic advantages for small series production and in general for all applications where high-speed cutting (HSC) would be too expensive or technically infeasible due to complex geometries.

Process reliability is better than that of other processes, which is of benefit in particular where expensive components are manufactured. Thus ECM guarantees optimum results in the machining of turbine disk rotor shafts by making sure, among other things, that the CNC control system stops the machining operation without causing damage to the workpiece when even the slightest technical problem occurs – for instance an unscheduled increase in the working current and the subsequent short circuit danger.

A Special Committee formed within the Verein Deutscher Ingenieure (VDI) is devoted to updating and revising Directive VDI 3401, which has been in force since 1993.

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